ELECTROMAGNETIC COMPATIBILITY

Standard EM Fields and Transfer Probe Standards

Project Leader: Motohisa Kanda

Staff: 5.5 Professionals, 0.5 Technician

Funding level: $1.1 M

Funding sources: NIST (54%), Other Government Agencies (45%), Other (1%)

Objective: Develop methods and techniques for establishing continuous wave and pulsed electromagnetic (EM) reference fields to 100 gigahertz; develop and improve NIST's antenna calibration services; perform research and development on probes to measure EM fields and power densities.

Background: Well-defined EM reference fields are necessary for antenna calibrations, antenna research and development, evaluation of EM field probes, and EM interference measurements. Commercial antennas and probes are generally unsuitable for metrology purposes, necessitating the development by NIST of probes which can serve as transfer standards necessary for traceability. This program area was ranked second among the top priority items by the participants of the recent EMI/EMC (electromagnetic interference/electromagnetic compatibility) Metrology Challenges for Industry Workshop, Boulder, January 1995. Thus, industry has clearly identified a need for EM field measurement capabilities that are traceable to NIST.

Current Tasks:

1. Develop methods for establishing standard EM fields

FY 1990	Developed standard field capability using pyramidal horns in the frequency range between 18 to 40 gigahertz.
FY 1991	Developed a time-domain method for evaluation of absorbers in the frequency range between 30 to 1000 megahertz.
FY 1992	Completed development of the spherical dipole standard field radiator.
FY 1993	Completed automation of the standard field facilities.
FY 1994	Analyzed anechoic chamber absorber and compared with measurements; initiated development of small-sample radio frequency absorber quality measurement system.
FY 1995	Performed a time-domain evaluation of the NIST anechoic chamber which revealed absorber and cavity characteristics.
FY 1996	Analyzed rectangular open-ended waveguides for improved standard field generation in the frequency range between 200 to 500 megahertz.
FY 1997	Extend NIST's standard field generation capability into the frequency range between 40 to 50 gigahertz.
FY 1998	Develop a radial, guided-wave cell for broadband field generation for frequencies up to 1 gigahertz.
FY 1999	Extend standard field generation capability to frequencies above 50 gigahertz.

2. Develop antenna and probe calibration service

FY 1992	Compared the standard-antenna and standard-field methods of antenna calibration and demonstrated close agreement.
FY 1993	Evaluated antenna-antenna interaction in vertical monopole calibrations and made instrumentation and mechanical improvements.
FY 1994	Developed and evaluated the standard dipoles and provided the results to voluntary standards committee.
FY 1995	Extended the vertical monopole calibration service to frequencies up to 300 megahertz.
FY 1996	Prepared documentation for loop antenna calibration service; developed a calibration service for radiated fields of standard source such as the NIST-designed spherical dipole radiator which is now a commercial product.
FY 1997	Extend monopole antenna calibration service from the current upper frequency limit of 300 megahertz to 3 gigahertz (i.e., 3000 megahertz).
FY 1998	Incorporate innovations in laboratory instrumentation to reduce measurement uncertainties in antenna calibrations.
FY 1999	Develop a new anechoic chamber with improved performance at lower frequencies.
FY 2000	Upgrade the NIST open area test facility and develop a new facility at a remote site (because of high ambient field in Boulder) for antenna calibrations at frequencies below 200 megahertz.

3. Develop EM field probes for transfer standards

FY 1991	Improved response of double-gap loop sensor for electric and magnetic responses.
FY 1992	Developed an improved electric-field multiprobe system with increased bandwidth and reduced field line pickup.
FY 1993	Developed a special antenna array system and receiver to detect low-level signals.
FY 1994	Performed theoretical and experimental evaluation of dipole electric field probe (dipole size: 2 centimeters).
FY 1995	Evaluated optically pumped, vertical-cavity, surface-emitting lasers for field probe applications.
FY 1996	Disseminated NIST-developed probe calibration techniques and uncertainty methodologies to standards committees.
FY 1997	Develop probes which will provide spectral information that can be used to discriminate against electromagnetic interference.
FY 1998	Evaluate and improve concentric loop antenna system for electric and magnetic field measurements.
FY 1999	Develop and evaluate improved near-field probes for electric and magnetic fields and power density.

Emission and Immunity Metrology

Project Leader: Motohisa Kanda

Staff: 5.5 Professionals, 0.5 Technician

Funding level: $1.1 M

Funding sources: NIST (52%), Other Government Agencies (47%), Other (1%)

Objective: Develop and evaluate reliable test and measurement methods for electromagnetic emission and immunity of electronic devices, components, and systems.

Background: U.S. industry needs to evaluate and control electromagnetic interference (EMI) that can impact economics and competitiveness, national security, health, and safety. The uncertainties of electromagnetic emissions and immunity measurements need to be rigorously quantified and, in some cases, reduced to make EMI measurement results reliable and useful. Major challenges are to provide reliable and cost effective test methods for a large frequency range (10 kilohertz to 40 gigahertz and, eventually, higher) and for large test volumes. Industrial clients are both manufacturers of electronic equipment, and electromagnetic compatibility and interference (EMC/EMI) test laboratories. NIST research, development, and measurement procedures provide guidelines for the entire U.S. EMC/EMI community.

Current Tasks:

1. Develop radiated immunity metrology

FY 1990 Developed and evaluated a hybrid chamber for broadband immunity measurement.

FY 1991 Developed time-domain method for broadband, radiated-field immunity measurement.

FY 1992 Evaluated the use of injection testing as a substitute for radiated immunity testing; developed and evaluated the use of the reverberation chamber for cable shield testing.

FY 1993 Analyzed and measured the shielding effectiveness of aircraft cavities; improved the time-domain method for shielding effectiveness measurements of thin sheets.

FY 1994 Analyzed and measured the crosstalk between transmission lines on printed circuit boards; developed the time-domain method for measuring the shielding effectiveness of aircraft cavities; evaluated frequency stirring for reverberation chamber measurements of radiated immunity.

FY 1995 Analyzed and improved the reverberation chamber method for measuring the radiated immunity of printed circuit boards; surveyed and analyzed measurement techniques for the shielding effectiveness of gaskets; developed a nested reverberation chamber measurement method for shielding effectiveness of optical fiber bulkhead connector systems.

FY 1996	Developed and evaluated alternative methods (time-domain and stepped frequency domain) for immunity measurements in reverberation chambers; analyzed a circular aperture for use as a standard in shielding effectiveness measurements.
FY 1997	Develop and evaluate a broadband method for measuring shielding effectiveness of gaskets; develop a shielding effectiveness measurement method for active electro-optical components.
FY 1998	Develop and evaluate new methods for radiated immunity measurements.
FY 1999	Extend radiated immunity measurements to higher frequencies (above 40 gigahertz).

2. Develop radiated emissions metrology

FY 1993	Developed and evaluated a three-loop system for low-frequency, radiated-emissions measurements.
FY 1994	Used the NIST spherical radiator to evaluate shielded-room measurements of radiated emissions.
FY 1995	Conducted a successful workshop on EMI/EMC measurement needs for industry; analyzed and measured printed circuit board radiated emissions in the NIST reverberation chamber.
FY 1996	Correlated reverberation chamber radiated emissions measurements to other facilities.
FY 1997	Incorporate time-frequency analysis in measurements for broadband, pulsed radiated emissions.
FY 1998	Determine how to combine radiated emissions from components to estimate total system radiation; develop and evaluate new methods for radiated emissions measurements.
FY 1999	Extend radiated emissions measurements to higher frequencies (above 40 gigahertz).

3. Improve measurement uncertainty estimates and methodology

FY 1996	Developed a general framework for evaluating the uncertainties in radiated emissions measurements; evaluated the uncertainty in field strength and uniformity for alternative mode-stirring methods in reverberation chambers.
FY 1997	Develop a general framework for evaluating the uncertainties in radiated immunity measurements; evaluate the uncertainties in field measurements made in anechoic chambers, transverse electromagnetic (TEM) cells, and hybrid TEM-reverberation chambers.
FY 1998	Evaluate uncertainties in emissions and immunity measurements due to the configuration of the test object; determine how to best combine separate uncertainties in field measurements to obtain total measurement uncertainty.
FY 1999	Extend uncertainty methodologies to the issue of repeatability from site to site and from facility to facility.
FY 2000	Evaluate the uncertainties of new facilities and methods of emissions and immunity measurements; extend uncertainty evaluations to higher frequencies (above 40 gigahertz).

Electromagnetic Properties of Materials

Project Leader: Claude Weil

Staff: 6.0 Professionals, 1.0 Technician

Funding level: $1.2 M

Funding sources: NIST (56%), Other Government Agencies (40%), Other (4%)

Objective: Evaluate existing and new measurement methods for characterizing the complex permittivity and permeability of dielectric and magnetic materials, as well as conductor surface resistance, over the radio-frequency/microwave spectral range 100 kilohertz to 100 gigahertz. Provide measurement services, standard reference materials (SRMs) and measurement fixtures to industry and others. Organize and implement measurement intercomparisons.

Background: Dielectric and magnetic materials have wide application throughout the electronics, microwave, communication and aerospace industries. Their applications include printed circuit boards, substrates, electronic and microwave components, sensor windows, antenna radomes and lenses, and microwave absorbers. Improved, low-cost and nondestructive measurement methods of known accuracies, covering a wide spectral and temperature range, plus SRMs, fixtures and services, are needed to support many specific industry needs. Intercomparisons provide quality assessments of national quality of material characterization capabilities.

Current Tasks:

1. Develop metrology for medium-to-high loss bulk solids

FY 1993	Completed new algorithms and software for the broadband transmission line technique and provided software to industry; Developed large-diameter (77 millimeter) coaxial air line technique and calibration methods; Completed study of air gap errors and evaluated use of soldered-in samples and holders in 7 and 77 millimeter coaxial geometries; Completed measurements of ferrite-loaded composite material used for feed-thru filters in automobile wiring harnesses and published results.
FY 1994	Selected and characterized candidate magnetic reference materials; Published results of intercomparison of dielectric measurements using the 7 millimeter coaxial air line in journal article.
FY 1995	Evaluated the performance of two nontunable stripline resonators for dielectric and magnetic measurements in the frequency range 150 to 2000 megahertz; Completed a measurement intercomparison with 6 laboratories using the stripline resonator; Completed intercomparison involving 15 laboratories of dielectric/magnetic measurements of ferrites using 7 and 14 millimeter coaxial air line technique.

FY 1996	Developed improved full-field solutions for a more sophisticated model of the 1-port open-ended coaxial probe that includes probe lift-off, finite layer thickness and metal backing; Performed measurements of lift-off error using 14 and 35 millimeter probes and developed new calibration methods; Developed techniques for speeding up numerical integration and wrote PC mountable, user friendly software for industry use; Published theory in journal article; In collaboration with Fields and Interference Metrology Group, developed free-field time-domain techniques for measuring the properties of inhomogeneous honeycomb panels over the frequency range 50-4000 megahertz.
FY 1997	Complete development of 2-port open-ended coaxial aperture technique for characterizing dielectric and magnetic properties of thin (250 µm) polymer sheets, using PC-mounted software as adapted from 1-port probe; Measure polymer films using 77 millimeter coaxial air line system and new 14 millimeter fixture and publish method; Complete draft of documentation for dielectric SRM service.
FY 1998	Begin documentation for SRM service in magnetic materials.
FY 1999	Develop methods for measuring inhomogeneous and anisotropic materials.

2. Develop high-precision resonator techniques for low-loss bulk solids

FY 1994	Evaluated dielectric rod resonator with Prof. J. Krupka of Poland; Characterized isotropic and anisotropic low-loss ceramics over broad frequency range, using variable conductor spacing and multiple modes; Developed new technique using thin rod sample at center of dielectric resonator for characterizing magnetic properties of demagnetized ferrites in the above-resonance microwave region, 2-20 gigahertz. Published this work in journal article.
FY 1995	Completed testing of a semi-confocal Fabry-Perot resonator for characterizing thin substrates at 60 gigahertz. Resonant modes were studied, material measurements performed; Evaluated a split-cylinder (Kent) cavity used for characterizing substrates and printed wiring boards (PWBs); Evaluated split-post dielectric resonator technique for characterizing PWBs and procured four fixtures operating at fixed frequencies of 1.2, 2.0, 5.6, 10.4 gigahertz; supplied identical fixtures to industry; Developed measurement capability, using ferrite rod inside dielectric rod resonator, for characterizing the complex permeability tensor of bulk ferrites when biased by a DC magnetic field of up to 800 kilo amp-turns per meter, obtained tensor data at 10 gigahertz, as a function of biasing field level.
FY 1996	Completed refurbishment and improvement of the NIST 60-millimeter diameter TE_{01p} mode cylindrical cavity to provide greater operating frequency range, 6-13.5 gigahertz, and more accurate loss factor measurements over a wider range of losses; Fixture is critical to planned NIST dielectric SRM service; Fabricated SRM coupons from samples characterized in cavity for industry; Began developing statistical protocol for certification of dielectric SRM service; Refurbished a tunable coaxial re-entrant cavity covering frequency range 80-250 megahertz and characterized PWB samples; Developed new full-field solutions for re-entrant cavity and investigating air-gap problems; Developed technique for measuring ferrite complex permeability tensor at low-bias field (< 80 kilo amp-turns per meter) measurements using circularly polarized waves at 2 and 10 gigahertz.

FY 1997	Complete study and measurements for the Full Sheet Resonance (FSR) method; Document Circle Fit Routine computer program for FSR measurements.
FY 1998	Develop fully confocal Fabry-Perot resonator operating at 77 and 94 gigahertz.
FY 1999	Determine feasibility of measurements at cryogenic and elevated temperatures.

3. Develop metrology for the microwave characterization of high-temperature superconductor (HTS) films and substrates

FY 1994	Developed a cryostat system, which operates over the temperature range of 4 to 120 kelvin with integrated sapphire rod resonator to measure both the surface resistance, R_S, of high temperature superconducting films at a frequency of 25 gigahertz, and the dielectric properties of substrate materials for HTS films; Evaluated a similar resonator for operating at a frequency of 10 gigahertz using a liquid nitrogen bath.
FY 1995	Completed variable-temperature measurements of yttrium barium copper oxide (YBCO) HTS thin films supplied by the NIST Electromagnetic Technology Division (814) and thallium films purchased from industry; Performed measurements at 77 kelvin of YBCO thick films supplied by industry; Investigated the dependency of R_S properties versus frequency at 77 kelvin in various HTS materials.
FY 1996	Began automation of cryostat system for ease of operation; Began uncertainty and error analysis for dielectric resonator system; In collaboration with Electromagnetic Technology Division, investigated variation of HTS film R_S with film thickness.
FY 1997	Procure very high-quality sapphire for dielectric rod fixture and measure losses using whispering gallery mode technique at cryogenic temperatures, apply data to uncertainty analysis; Complete automation of cryostat operation.
FY 1998	Develop methods for characterizing semiconductors and demagnetized ferrites at cryogenic temperatures.

4. Develop low-frequency impedance measurement techniques

FY 1994	Supported PWB project by evaluating accuracy of a commercially-available instrument that performs substrate characterization over the frequency range 1-1500 megahertz using a capacitive fixture.
FY 1995	Collaborated with MIT-Lincoln Lab (LL) and Genosensor Consortium by developing new automated techniques for DNA hybridization pattern detection; Completed initial permittivity measurements on DNA plus buffer solution and buffer alone, using 14 millimeter coaxial shielded-open technique, over range 0.3 -100 megahertz and found consistent differences in permittivity signatures.
FY 1996	Continued DNA measurements at low frequencies, 0.1-10 kilohertz using commercial liquid test fixture and NIST designed-fixture intended to overcome electrode polarization effects; Completed theoretical study of low-frequency relaxation in single and double stranded DNA.
FY 1997	Begin low-frequency DNA measurements using microelectrode array developed by LL and show whether same differences in permittivity signature exist at molecular dimension level.
FY 1998	Perform low-frequency DNA measurements using LL microelectrode array.

5. Develop metrology for characterizing thin-films

FY 1995	With Microwave Metrology Group, derived dielectric properties of thin substrates using coplanar waveguide transmission line structures; Developed low-frequency model for such structures.
FY 1996	Continued coplanar waveguide measurements and developed low frequency corrections to model; Initiated collaborative efforts to fabricate microelectronic test structures with SEMATECH and industry.
FY 1997	Continue program of collaboration with industry and NIST Electricity Division of fabricating coplanar waveguide test jigs for deriving dielectric properties of overlaid thin-film low-permittivity ("low-k") materials used in microelectronics packaging; Initiate development of techniques for characterizing unpatterned thin-film ferroelectrics under DC-biased conditions using 50-mm diameter mode-filtered cavity.
FY 1998	Begin investigation of methods for measuring thin-film ferrites under both demagnetized and DC-biased conditions at both cryogenic and room temperatures.
FY 1999	Investigate methods for measuring thin-film ferrites under both demagnetized and DC-biased conditions at both cryogenic and elevated temperatures.

6. Develop metrology for elevated temperature characterization of bulk solids

FY 1995	Completed survey of high-temperature (to 1500 ^{o}C) techniques available for characterizing bulk solids in the range 10 - 1000 megahertz; Completed detailed drawings of 1 gigahertz coaxial reentrant cavity and 14 mm coaxial air line fixtures capable of performing measurements over temperature range -100 to 200 ^{o}C.
FY 1996	Published the survey as NIST Internal Report 5045; Fabricated both fixtures at local machine shop and procured third split-post resonator fixture, capable of operating to 150 ^{o}C; Procured environmental chamber, capable of operating over range -80 to 300 ^{o}C and performed preliminary measurements at 100 ^{o}C.
FY 1997	Install laboratory exhaust fan and augmented utility supply in order to operate environmental chamber at maximum design temperature; Conduct material measurements.
FY 1998	Complete fixture for dielectric measurements at temperatures to 1500 °C.
FY 1999	Measure dielectrics at elevated temperatures using resonant fixture.